SCIENCE FOR GLASS PRODUCTION

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DYNAMICS OF THERMAL CONDITIONS OF MOLDS IN MOLDING GLASS ARTICLES

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It is proposed to introduce the concept of thermal stability in molds in the course of molding glass articles and a formula for calculating the stability coefficient, which will make it possible to model production conditions taking into account variations in the ambient temperature and molding duration.

Compression molding is one of the most efficient and cheap methods for producing household glass. This is a complicated physicochemical and thermal process in which the mold has a double function [1]. As a mechanical instrument the mold imparts a required shape to the glass melt, and as a heat-exchanging device in which metal is the working body, the mold intensely cools the glass melt surface layer, thus fixing the prescribed shape. Accordingly, correctly chosen geometric parameters of a glass-shaping mold have a deciding effect on its efficiency and service life [2].

Traditionally in designing glass-shaping molds, a designer does not perform a thermal design of the mold due to its high complexity and makes a decision relying on one's experience. The designer takes into account the fact that practical technological requirements allow for an admissible temperature variation interval on the mold inner surface in the course of molding. If the temperature on the mold inner surface exceeds the upper limit of this interval, the glass melt starts sticking to the surface. If the temperature is below the bottom limit of the interval, the viscosity of the adjacent glass melt layer rapidly increases, and then it becomes impossible to mold an article with prescribed qualitative or geometric parameters. Due to these difficulties, molds are designed by the "trial-and-error" method, i.e., an experimental mold prototype is first made, tested in molding, then certain correctives are introduced into the design, and trial molding is repeated until satisfactory experimental results are obtained [1].

There are analytical and empirical approaches to solving this problem. An assumption was made in [3, 4] that heat exchange in the molding of articles is stationary, that the physical properties of glass melt, such as heat conductivity, heat capacity, and density, do not depend on the temperature, and the heat transfer between the article and the mold is exclusively conductive. The considered articles were bodies of rotation. Differential equations for stationary temperature distribution were used in modeling the thermal field inside the mold.

Certain more precise mathematical models for calculation of thermal conditions were developed for specific articles with a convenient configuration. Thus, a spatial grid was developed in [5] to calculate molds for making cube-shaped glass blocks, and in [6] a mathematical model of a cylindrical glass pipe was calculated. USSR Author's Certificates Nos. 1321700 and 1261919 suggest producing thin-walled glass articles by varying the thermophysical parameters of different parts of the glass mold.

Thus, an improvement in the efficiency and service life of glass-shaping molds can be accomplished by decreasing the wall thickness and reducing the temperature difference between the outer and the inner wall [3].

However, a decrease in the wall thickness can lead to a substantial increase in the duration of molding or to impossibility of high-quality molding.

The studies in [2, 7] use the empirical method to identify the optimal mold design. It is proposed to use the specific weight notion, i.e., the ratio of the mold weight and the molded fluid glass weight to optimize the mold design (for blank molds this ratio ranges from 29.2 to 66.5) [2].

Analysis of these technologies made it possible to determine the ways for improving the methods for calculating the glass-shaping mold thermal conditions:

– to describe the molding process, it is necessary to take into account the thermophysical phenomena during the entire molding cycles, i.e. the non-stationary nature of the process;

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– since a wide range of articles is produced, it is necessary to develop algorithms and programs to calculate temperature fields in molds and articles of any configuration, not just those shaped as a body of rotation or a cube.

– by modeling thermophysical processes in molding, it is possible to optimize the mold design and reduce the expenses involved in the "trial-and-error" method.

The ambient temperature in molding varies due to weather variations. Convective heat transfer and heat exchange between the mold and the ambient medium vary due to the existence of draughts in production areas.

Let us qualitatively estimate the thermal conditions of a mold in molding.

Figure 1 shows the temperature field inside the mold wall in the course of heating. The process is non-stationary, and the mold layers adjacent to the glass melt get heated sooner, whereas the other mold layers due to the inertia of the heat transfer process (metals have high heat capacity) get heated at a slower rate.

When the article is removed from the mold, the layers near its inner surface are cooled faster. The temperature distribution inside the mold is reflected in Fig. 1*b*.

Thus, the stability of the temperature conditions in molding is ensured by the mold which has the function of a heat accumulator: i.e., in heating the mold absorbs excessive heat, and in cooling the mold releases heat. On variation of the ambient conditions, this results in insignificant temperature fluctuations in segment *0 – 1*, as well as modifications in the range and shape of the temperature curve in segment *1 – 2*.

However, as the wall thickness decreases, the thickness of segment *0 – 1* is reduced, and a certain moment may be reached at which the mold will not be able to maintain the thermal stability. Therefore, it is proposed to introduce the notion of the mold thermal stability, i.e., the ability of the mold to compensate for the effect of the ambient medium fluctuations.

In order to prevent the loss of stability in a mold, we propose introducing the stability coefficient which will limit excessive decrease in the wall thickness. This coefficient ought to take into account the thermal constants of the material and the process dynamics. Since heat expansion in the mold is proportional to the temperature conductivity of the mold material, we propose to calculate the stability coefficient in the following way:

$$K_{\text{stab}} = \frac{L_1}{aL_2},$$

where a is the temperature conductivity; L_1 and L_2 are the lengths of segments *2 – 1* and *1 – 0*, respectively (Fig. 1).

The segment length L_1 and L_2 determine the process dynamics, i.e., the duration of heating and cooling of the mold in different stages of molding. To calculate L_1 and L_2, it is suggested to assume that the mold walls are regarded as an infinite flat plate, and to select the sizes of the L_1 and L_2 segments in such a way as to achieve the maximum stability coefficient value. This will make it possible to simulate the most unfavorable molding conditions, i.e., variations in the ambient medium temperature, molding duration, etc.

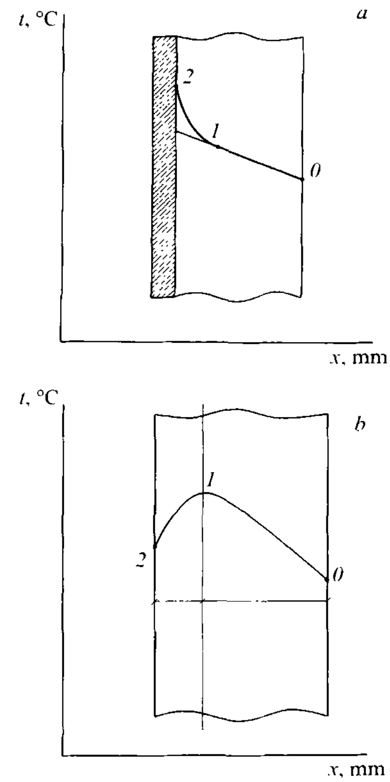

Fig. 1. Thermal field of mold wall in heating (*a*) and cooling (*b*).

At present the effectiveness and universality of the introduced parameters are being tested for a wide range of technological molding conditions and geometrical parameters of molded articles.

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